MILITARY METEOROLOGY*

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Since very early times the influence of the weather on military operations has been of great importance, and success or failure has many times been the direct result of weather conditions. But, because the scientific application of meteorology and its organization on a comprehensive scale are of recent development, modern military meteorology had its origin in the late war.

In the summer of 1917 it became evident that meteorological personnel and equipment were required by the American Expeditionary Forces in France. The interest of American meteorologists was aroused,[1] and arrangements were made to provide for the meteorological needs of the American armies in the field. Ideas as to the part meteorology played in the prosecution of war and as to the duties of meteorological personnel were, however, still very hazy, and actual work with the French and British armies was necessary to show how the meteorological units functioned. The actual day-to-day work began in April, 1918; and from that time until some months after the Armistice the meteorological work of the French, British, and American armies was carried on with cordial co-operation and mutual understanding. This account is an attempt to record some of the lessons learned.

THE MILITARY FACTOR

The military side of military meteorology cannot be neglected, although this phase of the matter, which looms so large in actual experience, can here have only passing attention. The reason for speaking of it here is that it is of vital importance in the selection and assignment of meteorologists for active military duty. Unless the meteorological officer in the field can handle his men, procure quarters and food for them, get his equipment, secure communication and transport service, and in general fit himself and

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[1] Several papers dealing with phases of military meteorology and with the meteorological service of the United States Army have appeared from time to time in the *Monthly Weather Review*. Reference may be made, for instance, to R. A. Millikan: Some Scientific Aspects of the Meteorological Work of the United States Army, Vol. 47, 1919, pp. 210–215; B. J. Sherry and A. T. Waterman: The Military Meteorological Service of the United States During the War, *ibid.*, pp. 215–222; H. G. Lyons: Meteorology During and After the War, *ibid.*, pp. 81–83. See also M. M. Welch: Recent Publications Relating to Military Meteorology, *ibid.*, Vol. 46, 1918, pp. 40–41.—EDIT. NOTE.

his command into the tactical organization with which he is associated, no amount of ability as a meteorologist will avail anything. Furthermore, he must understand the methods and problems of the officers charged with the development of the tactical situation or he cannot make his services as a meteorologist count in the prosecution of the war.

From a tactical point of view it is probably desirable to divide military meteorology into that applying to permanent positions, for instance coast defense commands, and that applying to mobile armies, best exemplified by an expeditionary force on foreign soil. The meteorological problems, however, are not widely different. The general problems of military meteorology are best exemplified by the requirements of an expeditionary force; because, while the meteorological problems of such a force can readily be applied to fixed positions, the conditions under which an expeditionary force operates, or is likely to operate, set limits to the methods employed.

Military meteorology falls into three rather clearly defined parts:

1. Statistical information, or past weather.
2. Current information, or present weather.
3. Forecasts, or future weather.

Statistical Information

Statistical information includes the mass of meteorological data which may be available for the region in question. Such information is valuable in connection with many military installations of a more or less permanent character and with the distribution of *matériel* and personnel, whether among training stations or on the battle front. In connection with statistical meteorology it may become necessary in the case of an expeditionary force to procure the information desired indirectly from observations on the character of plants, stream courses, etc. When an expeditionary force is being organized the meteorological officers attached to this force should accumulate as much information as possible regarding the conditions in the regions to which the force is to be sent. It is a question just how many data should be carried into the field. Field conditions do not readily lend themselves to transportation of voluminous records. On the other hand, the accumulation of material at the base in the home country is not of great value, owing to the fact that communications between the home base and the expeditionary force are apt to be overcrowded, and therefore the material accumulated is not readily accessible to officers in the field.

Statistical meteorology should be studied to such an extent that the meteorological officers can give definite information with regard to the important questions which are likely to arise. These questions will certainly concern such matters as the clothing and equipment of troops necessitated by the usual meteorological conditions. Extreme conditions are of less importance because a considerable amount of suffering by men and animals and serious disarrangement of transport by possible but not very probable

conditions must be expected in the case of any such expedition. The necessary preparation for expectable conditions will usually require all the energy of the general staff and impose such a strain upon communications with the home base that additional equipment to provide for unusual though possible conditions is not likely to be considered. Statistical meteorology will give such information as the probability of snow cover and the extent of such cover, the time of loss of leaves from trees or the changes in color of leaves, and similar matters of equal importance in these days of camouflage. It will show the time of freezing of rivers, important from the point of view of navigation and water supply as well as from that of transportation upon the ice. The probability and times of occurrence of snow and mud conditions with the resulting necessities of radical changes in transport methods will be shown by a proper study of the statistical records.

Before the medical department of an expeditionary force can make adequate arrangements for the care and transportation of the sick and wounded, or determine the number, design, and location of hospitals and the character and quantity of medical supplies, an adequate knowledge of the climate is required. While it is probably true that modern medical science has rejected the older ideas of climatic diseases, it is certain that weather conditions have an important effect on many types of disease; and weather knowledge is essential if the hospital rate is to be kept low and if the hospital facilities are to be adequate for the requirements.

Statistical meteorology is of particular importance in determining sites for the location of airdromes. After aircraft are in the air they can usually take care of themselves, subject of course to certain dangers which, however, are practically all less serious than enemy fire. The greatest difficulty in connection with aircraft comes in the take-off and the landing. Wind speeds which can readily be negotiated by planes in the air will cause serious crashes if they occur while planes are leaving the ground or alighting. Statistical meteorology can give valuable information in connection with the occurrence of such winds. As the control of a considerable part of these winds is topographic, a difference of a few miles in location may make an airdrome, considered as a harbor, relatively safe rather than dangerous. The direction from which dangerous winds come may indicate the proper orientation of hangars and buildings in order that they may be relatively safe.

Another point to be considered in the selection of the location for an airdrome is the occurrence of fog. Fog over an airdrome usually entirely obscures it from above and makes landing difficult and dangerous. Statistical meteorology can be of particular benefit by determining the positions where such fogs are least frequent. As the dangerous fogs are most often of the radiation type, the selection of hills which extend upward through the usual fog is indicated for the location of airdromes. Such hills, of course, should not be high enough to have dangerous wind velocities and, at least as far as airdromes within range of enemy artillery are concerned, should

not be distinctive landmarks, as these offer excellent targets. The dangers of the occurrence of fog vary with the type of airdrome. For instance, morning fogs, the usual radiation type, are probably most dangerous to night-bombing squadrons, as night bombing is usually undertaken on clear or partly clear nights and the planes wish to return home as late as possible, that is at just the time when radiation fogs are most likely to occur. Airdromes for day bombardment groups do not need such careful location with reference to fog conditions, although it is desirable to avoid them as far as practicable. The possibilities of locating airdromes for observation, reconnaissance, artillery adjustment, pursuit, and combat groups are more limited, because these airdromes must be nearer the lines than those for bombardment groups. However, the meteorological officer should be able to give information that would lead to the selection of the best one from a number of possible locations. Furthermore, as the lines are advanced it is a great convenience if the airdromes of combat groups can be occupied successively by artillery adjustment, observation, and bombardment groups.

The distribution of *matériel* and personnel within any zone of military operations is controlled to some extent by the meteorological characteristics of the zone as shown in the records of the past weather. It is known to every one that the distribution of clothing, food, shelter, heat, and light is so controlled. The record of prevailing winds by months is probably the best available guide for the concentration on certain parts of the battle front of chemical warfare troops and *matériel*. The position of gas shell dumps needs especial attention in this connection. Light data, the time of moonrise and moonset, of sunrise and sunset, and the duration of twilight have been found of value by searchlight units, anti-aircraft artillery, and night-bombing air squadrons in the distribution of lookouts and other personnel and in preparations for activity.

In addition to the service that statistical meteorology can render to other arms of the expeditionary force, the service it can render to the meteorological organization itself should not be overlooked. In order to provide the necessary information, proper sources for obtaining these data must be assured. Different arrangements must be made in different regions; if the expeditionary force is to operate in a friendly country with an organized meteorological service which can be counted on to supply information for the back area, it will not be necessary for such a force to operate as large a service of its own as it must when operations are carried on in a hostile country or one poorly provided with meteorological stations. Furthermore, the number, frequency, and location of meteorological stations will be governed to a considerable extent by the climatic conditions of the region in which operations are to be carried on.

Current Information

Current information consists of various types of data for use by all operating units, including especially aircraft, artillery, chemical warfare, and

sound-ranging units. Information for aircraft consists of wind data for levels at which planes are likely to fly or in which captive or dirigible balloons may be used. Such data are becoming increasingly important as aerial navigation is developed, and allowance for drift of airplanes must be made. The meteorological officer with current information regarding winds at various levels in his possession can advise flying officers of the most satisfactory levels at which flights between designated places should be made. Another type of information of value to aircraft is the altitude of the clouds.

In the case of artillery the temperature, pressure, humidity, and movement of the air to the height reached by a projectile in flight are needed in correcting for the effects of these elements when laying the guns. Air density is a function of the first three elements; within limits air viscosity varies rather directly with temperature, but corrections for this variation are small, although appearing in the firing tables. It should be stated parenthetically that the firing tables contain corrections for powder temperature, but this should be determined by a thermometer exposed in a charge because powder temperature does not in general vary with air temperature. Possibly the most important meteorological conditions affecting the projectile are those which are known as "ballistic winds." Meteorological conditions begin to act on the projectile from the moment it leaves the gun and continue to act until it lands. The effect of variations from standard conditions in any layer of air is proportional to the time the projectile spends in that layer, provided it passes twice through it; that is, when the target is at approximately the same level as the gun. When the target is to be reached before the projectile arrives at the highest point of the trajectory, as is usually the case with anti-aircraft targets, the effect of any layer is proportional to the time the projectile spends in it and to the time of its travel from this layer to the target.

In the case of ordinary artillery the importance of the upper layers of air is evident when it is considered that a projectile spends half its time in the upper quarter of its trajectory. In practice the air through which a projectile passes is divided into layers which are considered separately, weighted with the proper factors, and then combined for the total height of the trajectory. From this combination a single artificial wind direction and a single artificial wind speed affecting the projectile are computed and given to the artillery as a ballistic wind. This ballistic wind represents the total effect of the wind on the projectile from the moment it leaves the gun until it lands or bursts. Speed is essential in the computation of ballistic winds in order that the artillery may have this information while it is still valid and before conditions have perceptibly changed. In practice it has been found that observations once in four hours are usually sufficient.

A development of the World War was the accurate determination of the location of enemy guns from the rate and direction of the travel of sound.

It has been found by experiment that this is affected more by the air movement at about one hundred meters above the earth's surface, than that at higher or lower levels; it is also affected by the temperature and humidity of the air; these observations must be furnished promptly to the sound-ranging units if such units are to operate with the maximum of efficiency.

Current information enables the medical officers to make more effective plans for their work. For instance, weather which tends to keep men in billets or barracks increases the hospital rate. During the occupation of Coblenz the influenza rate could be forecast from the temperature, cold weather causing the men to stay indoors with the resulting spread of infectious diseases. The current weather information will give medical officers time to prepare hospital facilities and enable them to foresee the demands which will be made on them; this will permit the accumulation of adequate medical personnel and supplies at the points of greatest need. For example, wet weather with temperatures at or below freezing will greatly increase the sick rate of men in trenches, and preparations for the treatment of frostbite, trench feet, etc., can be made so that cases may be treated as they come in.

Station Equipment and Reports

The equipment consists of the ordinary station instruments, together with pilot balloon equipment for observing the movement of the upper air, which must be known up to the highest levels reached by aircraft or by projectiles. Owing to the conditions under which military stations must operate, the strongest type of equipment is required in order to prevent excessive breakage. It is, of course, obvious that stations operating in the neighborhood of artillery or in places likely to be shelled or bombed cannot depend upon aneroid barometers, as these instruments are damaged by concussion. In the case of a direct hit the equipment will be destroyed; replacement equipment must therefore be available at not too great a distance.

Conditions at forward positions make it necessary to take pilot balloon observations with one theodolite, although two or even three theodolite observations doubtless make for greater accuracy. It is often difficult enough to find one theodolite position sheltered from enemy observation—where observation means destruction whenever the enemy is so minded—and there is practically no possibility of finding two such positions within sight of each other and of providing the necessary equipment for communication between them. In this connection it is desirable to note that all units operating under control of the expeditionary force should be interchangeable, that is it should be possible to replace a front line unit with the one from the rear; therefore differences in method for different locations are inadvisable. Furthermore, meteorologists with actual experience in the area of military operations are of the opinion that two single theodolite observations

from different locations are worth more than a double theodolite observation at one location, although the latter may be somewhat more accurate.

In connection with supplying ballistic winds to artillery and actual winds at various elevations for the air service it must be remembered that the artillery may fire through clouds and that it may be necessary for airplanes to fly through and above clouds. The unit making the meteorological observations has the most information upon which to estimate conditions when direct observations are impossible. Air movement in and above clouds may be determined by the methods of "sounding by sound," which in brief consist in sending a bomb aloft by a balloon and bursting it at a height approximately determined. The exact position in space at which the burst occurs can be determined by sound-ranging methods, and the exact height and the horizontal drift of the balloon from the time of release to the time of the explosion of the bomb can be computed. When such information is not available an alert meteorological observer can secure information which will enable him to estimate conditions with considerable accuracy. During cloudy weather he should watch for breaks in the clouds and attempt to get a balloon through these breaks even though the time for a regular observation has not arrived. Anti-aircraft guns may be fired through breaks in the clouds, and the drift of the smoke from the burst may be followed with a theodolite. The drift of clouds may be observed and the approximate height estimated. All reports from neighboring stations, friendly or enemy, should be recorded; as ballistic winds are usually sent to the artillery by radiotelegraphy, enemy information can be obtained if the meteorological observer takes pains to ascertain the times of sending and the wave length. His own equipment will enable him to receive the messages, and if the intelligence service of his army cannot provide him with the code used his ingenuity will enable him to work it out. From these miscellaneous data a successful estimate may be made. The firing tables issued to the artillery provide for meteorological data, and some value must be used for this term.

Weather Forecasting

Military forecasting should not be essentially different from any other sort of forecasting. Successful forecasting for the staff officers charged with the control of operations does, however, depend on an appreciation of their problems by the officer making the forecast. A forecast for military operations should be stated as concisely and definitely as possible; in fact, it is best to make direct positive statements of the future weather. Operations officers must take chances with many elements of which the weather is only one; what they require is the best estimate of the situation and some idea of the accuracy of the estimate. It is far better to state positively what the weather will be and to follow the definite forecast by a statement that the chance of its being correct is ten to one, five to one, or three to one, as the case may be.

Special forecasts may be made for all sorts of special operations. For example, the offensive use of gas requires detailed forecasts of local air movement in restricted localities; this often calls for special observations in detail at frequent intervals. The artillery frequently find it advisable to institute firing programs at particular times, such as dusk or dawn; the meteorological service will frequently be called upon to make special forecasts of visibility for these programs. Forecasts of the character of the night, whether clear, cloudy, or with broken cloud, are particularly important in planning offensive bombing operations by aircraft or in arranging for defense against possible enemy raids. For instance, if the conditions on the Lorraine front in the fall of 1918 indicated a moonlight night with broken cloud and a moderate west wind at reasonable flying levels, an enemy raid was practically certain and could be forecast with great accuracy; furthermore, with a little knowledge of the enemy's habits together with observations of his aerial activity during the preceding day, the point of the raid could generally be forecast.

In forecasting for an expeditionary force it is obvious that there is likely to be little opportunity for dependence on weather types and hence for empirical forecasting based on the resemblance of the current map to a type in the files. In his home country the forecaster is in touch with the maps of past years; all meteorological services have built up files of maps and in many cases have selected type maps which may be and usually are used, consciously or unconsciously, by the forecasters. In a region new to the forecaster this procedure is far from convenient and often impossible. Furthermore, the possibility of military activities in a region without published maps must be considered.

With the advance from empirical to rational methods in forecasting, this is not so great a difficulty as might appear. There can be little doubt that the future weather is the result of physical and dynamic processes which are going on currently, and current meteorological information and that of the immediate past should furnish all the data necessary for a proper forecast. It is a question whether forecasting has as yet reached a stage where this is possible, but experience with the American Expeditionary Forces in France and Germany leads to the belief that forecasting, at least for an expeditionary force, should be on this basis. Such a point of view, of course, lays more emphasis on theoretical physics than upon weather types and requires fundamental training in meteorological physics and the dynamics of fluids rather than experience in forecasting in the home country.

Distribution of Stations

The number and distribution of the stations operated by the meteorological service of an expeditionary force will depend upon many factors. In the back area the number will probably be about the same as would be required for peace-time meteorological information; if there is a suitable meteorologi-

cal organization already in this area its stations may well be used. It will probably be necessary to add a few stations at special points, such as artillery and other training fields and airdromes. The stations in the back area should serve for training meteorological personnel and supplying information to the military units stationed in this area as well as for making the fundamental observations upon which the forecasts are based. In the area of military activity there must be a greater density of stations. There should be at least one station in each region where airdromes are located, and stations to supply ballistic winds to the artillery and information to the sound-ranging and other services must be located along the front in sufficient numbers to give adequate information. The number will not be the same in different regions but will to some extent be governed by the general climatic conditions.

Furthermore, it has not yet been found practicable to operate a military meteorological service solely on the basis of the meteorological conditions encountered. Practical problems of tactical organization make it desirable that the meteorological units bear a rather definite relation to the tactical divisions by which the army operates. Perhaps the most usual and satisfactory organization is that of a first-class station completely equipped for all observations and for weather-forecasting attached to each field army. This station should be in close touch with the army headquarters and should have telegraphic communication with the stations in the back area to provide it with the information necessary for forecasting. In addition to the forecasting station in the army area, it will be found desirable to establish from two to five or more stations in the same area to serve the artillery and other units. Inasmuch as tactical considerations play a very important part in the organization of the army area, the most convenient arrangement appears to be the assignment of one of these substations to each army corps. The conditions existing in the particular region will undoubtedly serve to modify the general plan; but if equipment and personnel are provided for a first-class forecasting station attached to army headquarters and an observation station equipped for surface and upper air observations for each army corps, it will be possible in nearly all cases to provide the forward area with an adequate meteorological service. The back area is a regional problem and from a tactical point of view must be handled in much the same manner as the lines of communications of the armies.